Research on non-motor vehicle parking around subway stations in urban suburbs based on microsimulation

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Abstract. As an important mode of transportation for the "last kilometer" of rail travel, due to the long distance between stations in urban suburbs, the demand for non-motor vehicle shuttle parking is increasing, and the unreasonable division of parking areas leads to the decline of traffic efficiency around subway stations. In this paper, the Chengxian subway station of Dongda in suburban Nanjing is selected as the research object. Through field investigation and data collection, Anylogic simulation software is used to conduct mixed traffic simulation, propose optimization strategies, and conduct comparison and test of schemes. The results show that by optimizing the parking of non-motor vehicles and increasing the effective road width, the pedestrian density can be reduced effectively and the travel time can be shortened by 7.35%. This study can provide reference for the planning and construction of non-motor vehicle parking areas around subway stations and improving the traffic efficiency of walking space.

Keywords: suburban metro station surrounding; non-motor vehicle parking; mixed traffic simulation; traffic efficiency; scheme optimization

1 Introduction

In the context of travel in the dual-carbon era, the number of non-motor vehicles in cities is increasing, which brings convenience while the contradiction of planning and parking is also increasingly apparent.Under the influence of factors such as unclear demarcation of parking Spaces, unbalanced demarcation of parking Spaces and chaotic placement, the problem of non-motor vehicle parking

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around subway stations in suburban areas has become an important content that needs to be solved urgently in urban planning and construction.

The problem of non-motor vehicle parking has been the focus of many researches. This paper discusses the significance of regulating urban non-motor vehicle parking and the causes of urban non-motor vehicle parking[1]. Starting from the aspects of concept, facilities and management, the parking management strategy of electric bicycles around railway stations is systematically proposed[2]. In addition to the management level, the reasonable setting of non-motor vehicle parking area is the premise to solve the traffic congestion and improve the traffic efficiency, so it needs to be considered from the practical level, and the prerequisite for realizing this goal is to understand the riding behavior, walking behavior and parking behavior of non-motor vehicle users. Traffic simulation, as an important tool for evaluating and optimizing traffic systems, has attracted more and more attention from the academic community[3]. By studying non-motor vehicle individuals and their mixed flow characteristics, non-motor vehicle simulation models are established to rationally allocate non-motor lane resources and solve urban traffic problems[4]. By establishing the simulation model of mixed traffic flow in the parking section of single-vehicle road, the influence of non-motor vehicle flow and different parking forms on mixed traffic flow is analyzed[5]. By establishing a microscopic traffic flow model of on-road parking behavior, the impact of on-road parking on traffic flow and parking policies is simulated and studied, and management strategies and optimization measures for on-road parking are proposed[6]. Social force models of pedestrians, motor vehicles and bicycles are established to simulate mixed traffic and reflect different behavioral characteristics of various road users[7]. Bicycles mix with motor vehicles and pedestrians, affecting road traffic order and reducing road capacity, which may induce certain traffic accidents[8]. Therefore, it is urgent to improve the current situation of non-motor vehicle parking around subway stations in order to promote the traffic efficiency of walking space.

This study aims to propose a new idea to study the mixed traffic around metro stations in urban suburbs based on the social force model, combining cycling behavior, walking behavior and parking behavior to explore the impact of road and parking area Settings on the walking efficiency around metro stations, so as to provide a realistic basis for optimizing the safe traffic environment for non-motor vehicles to ride and walk. Promote sustainable urban transport development.

2 Case study

2.1 Study subjects

The problem of non-motor vehicle parking around subway stations in suburban areas is becoming increasingly obvious, and there has been a lack of targeted research. Therefore, the non-motor vehicle parking area around Dongda

Chengxian subway station in suburban Nanjing is selected as the simulation space. There are 4 subway entrances and exits and an auxiliary elevator entrance and exit at this subway station. There are a large number of non-motor vehicle parking areas around the station, and there are a large number of non-motor vehicle cycling and walking phenomena, which will cause serious congestion problems. The selection of this station has typical significance for this study.

2.2 Data Collection

Field research was conducted at the example site during the morning peak period of two consecutive weekdays from 7:30 to 8:30. In this time period, residents have the highest requirements for traffic efficiency. Firstly, the non-motor vehicle parking area and the maximum capacity of each parking area are measured on the spot. Secondly, through field observation and video processing technology, the behavior characteristics of non-motor vehicle cycling and walking in the natural state and the number of cyclists and walkers from all directions were recorded. Then, according to the field investigation statistics and literature reference, the age composition, walking speed, cycling speed, pedestrian size and non-motor vehicle size of the commuter population were determined, and the obtained data were used as parameters for mixed traffic simulation.

2.2.1 The number of people flow

There are 9 main starting points (labeled 1, 2, 3, 4, 5, 6, 7, 8, 9) in the basic space, and the number of people flow is investigated at each starting point. The survey method adopted is the direct counting method, taking the number of people passing every hour as the basic unit, according to the number of people in the morning peak hours of working days in a week(Table. 1).

Table 1 The number of people at each starting point during the working day commute

Ways	1	2	3	4	5	6	7	8	9
Walk	41	70	52	80	91	60	280	602	80
Bike	8	5	18	11	7	9	18	14	17
Electric vehicle	61	55	140	89	72	51	142	184	143
Total	110	130	210	180	170	120	440	800	240

2.2.2 Pedestrian flow composition

There is a significant difference in the age composition of subway passengers in the morning rush hour. The study on the age composition of commuters around the example stations has a crucial impact on the setting of walking and cycling speed parameters and the subsequent simulation modeling. According to the field survey and visit to the morning rush hour, the statistical data of passenger flow are shown in Figure 4-21. In Dongda Chengxian subway station, 11.1% of people are under 20 years old, 53.8% are between 20 and 39 years old, 31.9% are between 40 and 59 years old, and 3.2% are over 60 years old. According to the survey statistics, the commuters in the example stations in the morning peak hours are mainly young and middle-aged people between 20 and 59 years old.

2.2.3 Pedestrian flow speed

The parameters of the non-motor vehicle social force model mainly include velocity and the related parameters of the interaction force and the boundary force. Under barrier-free conditions, the pedestrian's stride length is about 0.75m. According to the data obtained from relevant research and field observation data, the expected speed of pedestrians in the non-motor vehicle area around subway stations in the morning rush hour is 0.7-1.7m/s, and the expected speed interval of non-motor vehicles is set at 1.3-3.5m/s.

2.2.4 Size of pedestrian flow

Most of the pedestrians in the morning rush hour of the railway station area are for commuting purposes. The survey found that there are almost no pedestrians carrying large luggage, only carrying backpacks or satchels, and the impact on pedestrian size is negligible. Therefore, the pedestrian size in this paper is based on pedestrian shoulder width as the simulation parameter. According to the Human Body Size of Chinese Adults (GB/T 10000-1998), the average shoulder width of Chinese adult males aged 18-60 is 375mm, and that of adult females aged 18-55 is 351mm. The size of non-motor vehicle will affect the avoidance distance, and then affect the interference degree of non-motor vehicle workshop, which is one of the factors that must be considered in the study of non-motor vehicle operation rule and the design of non-motor lane. According to the research and investigation, the average length of the electric bicycle body is 174cm, and the average width of the body is 64cm, which is significantly larger than the length of the conventional bicycle 170cm and the width of 58cm.

2.2.5 Other parameters

By measuring the area of each non-motor vehicle parking area on the spot, combined with the size of non-motor vehicles, the maximum capacity of non-motor vehicle parking area at each station can be obtained. In addition, the subway station has an auxiliary elevator entrance, the running time from the ground floor to the negative first floor is 5s, and the average waiting time is 20s, which is also an indispensable important parameter in the simulation.

2.3 Establishment of simulation model

Mixed traffic flow simulation refers to the modeling of traffic scenarios involving multiple traffic participants. In this study, Anylogic is selected as the simulation platform. The combination of walking and cycling in the established simulation model integrates more complex individual behaviors and activities than the traditional traffic simulation model.

2.3.1 Construction of basic simulation environment

Through the field measurement around Dongda Chengxian subway station, the environment model of non-motorized traffic system is established to provide a simulation system environment for the subsequent simulation.The elements involved in this step include obstacles, road network, parking area, starting and ending point of people flow, etc(Fig. 1).

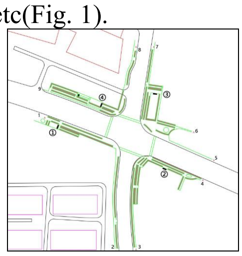

Fig. 1 Base scene

2.3.2 Behavioral flow modeling

In this study, the simulation of traffic behavior logic is the focus and difficulty of this study. Walkers walk directly from the initial point to the vanishing point, while non-motorized cyclists ride from the initial point to the non-motorized area, park the vehicle and then walk to the vanishing point. In the process of behavior modeling, it is necessary to test the passing behavior to ensure the authenticity and accuracy of the simulation effect, and to adjust and modify the situation in the model that is very different from the reality. The following is part of the behavior flow chart in this study(Fig. 2).

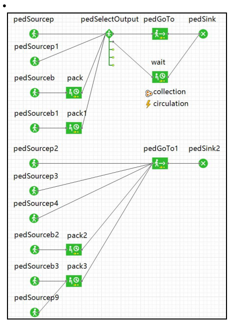

Fig. 2 Behavior Flow Chart

3 Simulation results and reason analysis

In this study, two commonly used traffic indicators are selected, one is travel time and the other is crowd density.

Transit time refers to the time spent by passengers in the process of system appearance and disappearance, and its index can be obtained by Anylogic software. The shorter the passing time, the greater the traffic capacity of the section, indicating the better the passing efficiency.

Crowd density refers to the number of people per square meter in the passing process, and its index can be automatically generated by Anylogic software about the crowd density map in any time period in the study area.

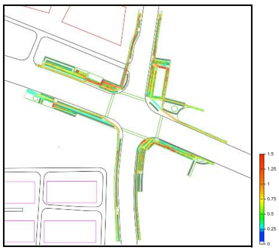

Fig. 3 Simulation 30min

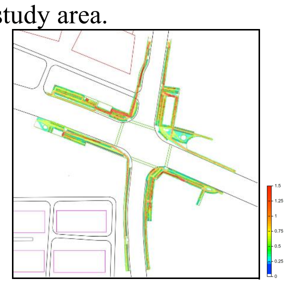

Fig. 4 Simulation 60min

A comparative analysis of the simulation diagram of the morning rush hour traffic system around Dongda Chengxian subway station shows that there is no significant change in the regional pedestrian density during the morning rush hour. The simulation 30min is 8:00 a.m. in the morning rush hour, and the area with high pedestrian density is mainly concentrated in the subway entrance and parking area(Fig. 3).Simulation 60min is 8:30 a.m. in the morning rush hour, and the crowd density at this moment is slightly higher than that at the simulation 30min, and the crowd density in the parking area increases significantly(Fig. 4).

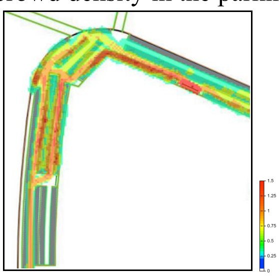

Fig. 5 Simulation 30min

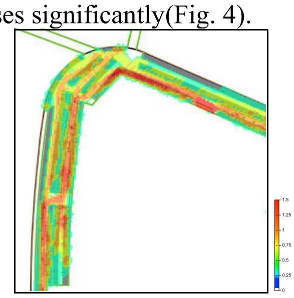

Fig. 6 Simulation 60min

Subway Exit 2: The simulation time of 30 minutes is 8:00 a.m. in the morning rush hour, and there is a density imbalance in the study range(Fig. 5).The simulation time of 60 minutes is 8:30 in the morning peak, and the regional pedestrian density increases significantly(Fig. 6). Concentrated congestion areas are corners and part of the road. The main reason is that there is a closed phenomenon at the end of the parking area, and unreasonable parking encroaches on the turning area, which is not easy to pass.

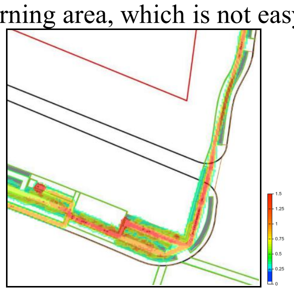

Fig. 7 Simulation 30min

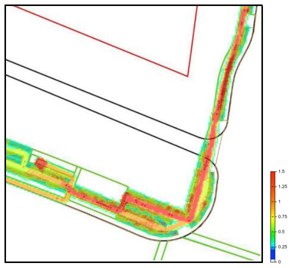

Fig. 8 Simulation 60min

Subway Exit 4: The simulated 60min(Fig. 8) is 8:30 a.m. in the morning rush hour, and the pedestrian density in the area has no significant change compared with the simulated 30min(Fig. 7). From the perspective of the overall population density, there is a large area of crowd crowding in the study area. The area of concentrated congestion area is the site entrance and exit and too narrow passing road. The main reason is that the effective width of some non-motorized lanes is too low, which is not conducive to the turnover of non-motor vehicles, thus affecting the traffic efficiency.

The statistical data of traffic time are shown in the table(Table. 2).

Table 2 The statistical data of traffic time

Average duration (s)	Port 1	Port 2	Port 3	Port 4
Riding	118.67	125.83	98.4	120.23
Walk	158.12	106.93	82.68	124.04
Passable	136.22	118.81	88.4	122.91

4 Optimization strategy and simulation comparison

4.1 Optimization Strategy

Traffic is the basic function of traffic space, and the optimization of parking space should fully consider traffic efficiency. In the current situation, there is an unreasonable division of non-motor vehicle areas, which is not only conducive to the distribution of people, but to a large extent, it causes interference to the traffic flow line and intensifies the congestion near the entrance and exit. In the case of meeting the parking demand, the non-motor vehicle parking area of the station should be laid out according to the principle of traffic priority, and reasonable regional division should be carried out in the space to ensure that the needs of traffic, non-motor vehicle parking and pedestrian stay are met.

4.1.1 Reasonable division of parking areas to enhance road connectivity

The higher the connectivity of the road network system around the station, the stronger the accessibility of the walking space, and the higher the accessibility of the rail subway station. The end road or the broken road has little effect on the evacuation of pedestrian flow, and will affect the efficiency of pedestrian flow to a great extent during the period of continuous increase of pedestrian flow in the morning peak. Strengthen the communication of end-end roads or broken roads, play the role of road microcirculation, improve the connectivity of the road network, and improve the traffic efficiency of the traffic system. In the optimization plan, adjust the unreasonable parking Spaces, increase the connectivity of the road, and improve the parking efficiency and traffic efficiency of non-motor vehicles.

4.1.2 Moderately increase the pedestrian space scale of subway stations

On the one hand, the current "Urban Road Engineering Design Code" for the width of the sidewalk is mostly based on the grade of the road design, but there is no clear solution for the scale of the walking space around the subway station; On the other hand, in the preliminary design of urban planning, the influence of traffic facilities on the carrying capacity of the walking system is not fully considered, which results in the congestion and chaos of the walking system around the subway station. When the non-motor vehicle traffic volume is constant, the wider the non-motor vehicle lane, the smaller the non-motor vehicle traffic volume per unit width, and the lower the probability of non-motor vehicles occupying the road. In the optimization scheme, the non-motorized lane can be expanded to ensure the effective width of the non-motorized lane.

4.2 Simulation and comparative inspection of the improved scheme

Scheme 1: According to the above optimization and improvement measures for Dongda Chengxian Subway Station, simulation modeling is carried out on the optimized non-motor vehicle parking space to test the results of the optimization scheme(Fig. 9).

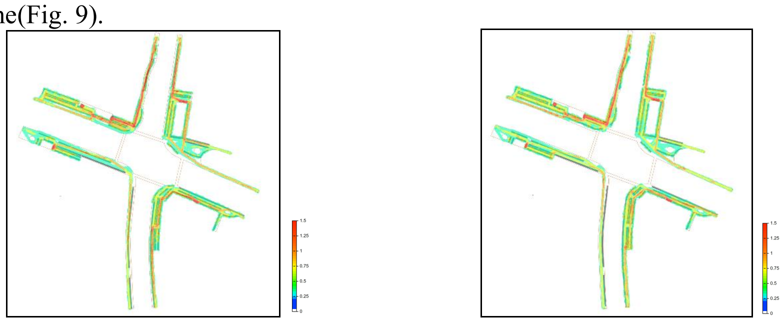

Fig. 9 Optimize the before and after chart

The optimization plan is simulated and tested. The pedestrian density map is output at the peak of the pedestrian density. Compared with the previous pedestrian density map, it can be found that the original location with excessive pedestrian density in the region has been significantly alleviated, and the traffic efficiency has been greatly improved.

Table 3 The statistical data of traffic time

Average duration (s)	Port 1	Port 2	Port 3	Port 4
Riding	112.41	111.45	92.32	112.9
Walk	124.23	103.78	79.26	115.75
Passable	118.29	108.33	83.97	114.8

Compared with the traffic time before optimization derived by anylogic, the traffic time of both cycling and walking is significantly shortened. The total average travel time is shortened by 7.96s, in which the average walking time is shortened by 7.34s and the average cycling time is shortened by 8.8s(Table. 3).

Scheme 2: Optimize again on the basis of plan 1, and adjust some crowded parking areas while ensuring a constant maximum number of parking. The results show that the average time of total passage is shortened by 0.79s.

In this study, we simulated three scenarios. One scenario is the real status quo, and the other two scenarios are the optimized scenarios. Before the simulation, we have measured various data around Dongda Chengxian subway station on site, including the width of different lanes, the size and maximum parking capacity of parking areas, the number of pedestrians and cyclists in each exit direction during the morning rush hour on working days, and set parameters such as cycling, walking speed, and waiting time for the auxiliary elevator entrance at Exit 4. Finally, both of these conditions were simulated.

The results show that the comparison before and after optimization reflects the improvement of traffic efficiency under the guidance of the optimization strategy in this paper to a large extent. As can be seen from the density map, the original location of excessive traffic density has been significantly alleviated. According to the above statistical data of average passing time before and after optimization, the average passing time after optimization is reduced by 7.35%.

5 Conclusion

The main findings of this study are summarized as follows: reasonable arrangement of non-motor vehicle parking Spaces and appropriate increase of effective road width can significantly reduce traffic density and save travel time.

The new method proposed in this paper combines real-world data with agent-based modeling technology to realize advanced hybrid simulation of non-motor vehicle riding and walking behavior, including non-motor vehicle riders' behavior of walking after parking their vehicles, which can more clearly realize the information exchange between different individuals and the interaction between individuals and the simulated environment. This can provide a methodological reference for the future study of the traffic efficiency of the pedestrian system. Because the periphery of suburban subway stations undertakes the commuting needs of pedestrians to the urban area during the morning rush hour, and there are common problems such as crowding and low traffic efficiency around the station, this method is also suitable for solving the traffic efficiency problems around suburban subway stations in other cities, which provides new thinking and inspiration for the future spatial planning and design of parking around similar stations in cities. In this way, planners can dynamically simulate the traffic conditions in the non-motorized parking area around the site, so as to rationalize the transportation infrastructure, and also identify and optimize the current transportation system.

However, there are still some disadvantages. The parameter setting in the simulation model requires more experience to make the simulation results more objective and accurate. In addition to this, the modeling did not take into account the small number of people leaving the suburban subway station during the morning rush hour. Through further research on these directions, we can provide effective theoretical support and technical approaches for the improvement of urban non-motor vehicle parking.

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